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EFFECT OF CYCLIC HEAT TREATMENT ON THE DIMENSIONAL STABILITY OF METALS AND ALLOYS WHEN A LOAD IS CONTINUOUSLY APPLIED

By

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EFFECT OF CYCLIC HEAT TREATMENT ON THE DIMENSIONAL STABILITY OF METALS AND ALLOYS WHEN A LOAD IS CONTINUOUSLY APPLIED

A. A. Bochvar, et al.

Cyclic heat treatment (c.h.t.) causes in all metals and alloys residual changes of dimension in the tested specimens or articles. These changes attain very high values under cyclic heating and cooling conditions [1].

The residual dimensional changes occurring in articles under the effect of c.h.t. cause enormous damage in the most different areas of modern technology and, in particular, in that of reactors and nuclear piles [3, 4]. Therefore a study of the factors affecting residual changes in the shape of specimens and articles undergoing c.h.t. and of measures against this injurious phenomenon has great practical and theoretical significance.

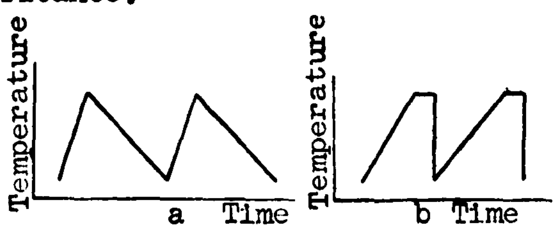

Fig. 1. Graph of cyclic heat treatment. a) uranium; b) aluminum, α- and β-brass, (α+b)-brass.

The present work investigates the influence of a continuously applied load on the dimensional stability of various metals and alloys in c.h.t. Flat specimens of the same shape with an over-all length of 100 mm (length of working section 40 mm, breadth 8 mm, thickness 2 mm) made of uranium, aluminum, zinc, and alloys of copper and zinc of varying composition. The uranium specimens were tested in a special set-up under vacuum (10^{-5}mm Hg); and all the others, unprotected from oxydation—heated in air and cooled in water. The specimens were cyclically heat treated in the temperatures ranges 180 to 550° for uranium, 20 to 400° for aluminum, 20 to 300° for zinc, 20 to 600° for alloys of copper and zinc. The temperature of the specimens was checked by thermocouples welded to them at three points.

Figure 1 presents a graph of the c.h.t. The magnitude of residual deformation was ascertained in the specimens:

1. after c.h.t. without application of an external load;
2. after c.h.t. with application of tension during the heat cycle;
3. after tests for creep at a temperature equal to the top cyclic temperature.

The duration of these tests was equal to the complete period of the heat cycle multipled by the number of cycles. The size of the load in c.h.t. under load and in the creep tests was the same.

Textured uranium rolled in the α-phase region and untextured uranium annealed in the γ-phase region and hardened from the β-phase region were tested. The textured uranium specimens were cut out with and across the direction of rolling. As is known, a sheet of textured uranium rolled in the α-phase region lengthens along the direction of rolling and contracts perpendicularly thereto under the effect of c.h.t. at certain parameters of the heat cycle.

The post-test results of measuring the dimensions of the uranium specimens, cut across the direction of rolling at 300° with 60% reduction, are shown in Fig. 2. As is evident, c.h.t. without load caused contraction in length of the transverse specimens, but the tests for creep showed a slight increase in their length. C.h.t. with a continuously applied load led to significant residual deformation in the direction of application of the external load. Specimen 2, for example, after c.h.t. in the 180-550° range without load contracted by 1.65%; specimen 3 after creep testing lengthened by 0.2%; but specimen after c.h.t. with a continuously applied stress of $\sigma = 1.25$ kg/mm² not only did not contract, but lengthened by 6.5%, notwithstanding that the negative effect of the dimensional changes in c.h.t. exceeds in absolute value the positive effect in creep.

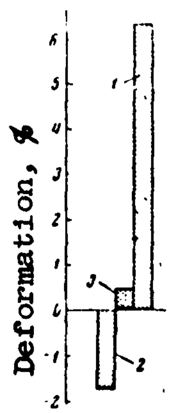

Fig. 2. Effect of a continuously applied stress (1.25 kg/mm²) on residual deformation of uranium rolled in α-phase region during 200 heat cycles in the 180-550° range and in absence thereof. (Creep tests at 550°.) Specimens cut out across the direction of rolling. Residual deformation of the specimens after 1) heat cycles with continuously applied load, 2) heat cycles without load, 3) creep tests with $t = 550°$ and $\tau = 3$ hrs.

The effect during c.h.t. of the amount of applied tensile stress on residual deformation of uranium was investigated in specimens which decrease in length in c.h.t. without load. The uranium was rolled at 500° with a reduction of 85%; the specimens were cut out across the direction of rolling (Fig. 3). As is evident from Fig. 3, change in the sign of deformation is observed at $\sigma = 350$ g/mm². With external

tensile stresses less than 350 g/mm² the negative effect of dimensional changes during c.h.t. predominates over the positive effect of dimensional changes under the influence of tension.

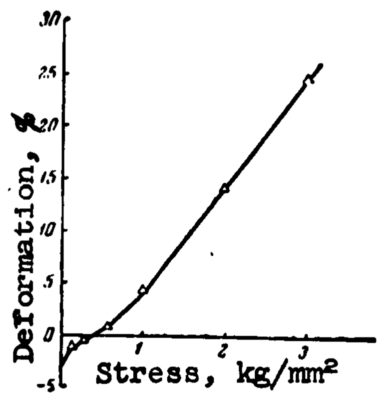

Fig. 3. Relation of residual deformation in uranium rolled in the α-region to magnitude of stresses after 200 heat cycles in the 180-550° range. Specimens cut out across the direction of rolling.

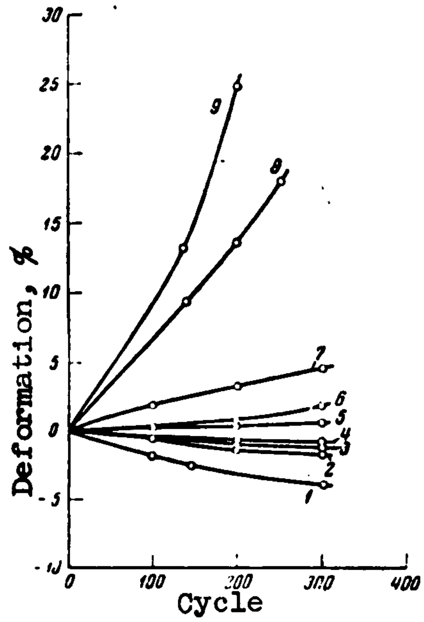

Fig. 4. Effect of applied tensile stress on residual deformation of uranium rolled in the α-region with c.h.t. in the 180-550° range. Specimens cut out across the direction of rolling. σ in kg/mm²: 1) 0; 2) 0.1; 3) 0.2; 4) 0.3; 5) 0.4; 6) 0.5; 7) 1; 8) 2; 9) 3.

The dependence of residual deformation in uranium on the magnitude of the stresses and the number of cycles is shown in Fig. 4. When the stress is σ = 300 g/mm², the dimensions of the specimen stay practically stable and change little when the number of cycles is increased.

Tests of the uranium specimens cut out along the rolling direction (rolled at 300°, reduced by 60%) showed that c.h.t. and creep caused by external tension both change the dimensions of the longitudinal specimens in the same direction. C.h.t. and stress result in a residual deformation several times larger than total residual

deformation from c.h.t. alone without load and from creep alone at a temperature equal to the highest in the cycle accompanied by corresponding stress (Fig. 5).

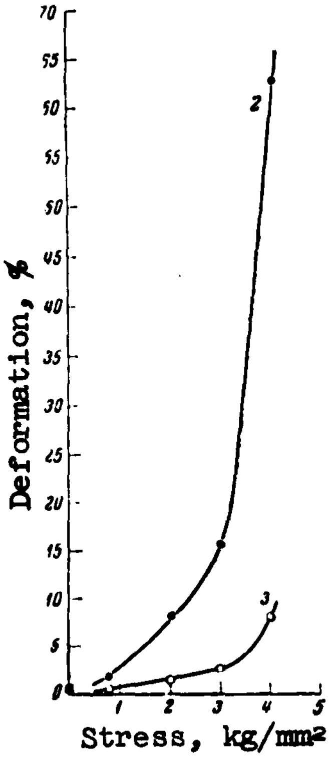

Fig. 5. Effect of continuously applied stress on residual deformation in uranium rolled in the α-phase region. 140 heat cycles in the 180-550° range. Creep tests at 550°. Specimens cut out along the direction of rolling. Residual deformation of specimens after 1) heat cycles without load, 2) heat cycles with continuously applied load, 3) creep test with t = 550° and τ = 14 hrs.

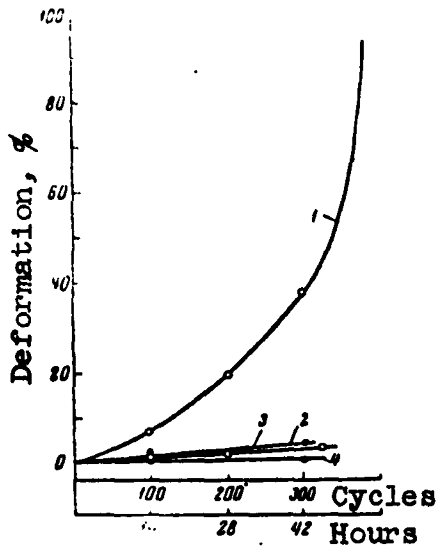

Fig. 6. Effect of preliminary heat treatment on residual deformation in uranium during c.h.t. in the 180-550° range. Residual elongation in uranium 1) quenched from β-phase after c.h.t. with stress σ = 2 kg/mm², 2) quenched from β-phase after creep tests with t = 550° and σ = 2 kg/mm², 3) annealed in γ-phase after c.h.t. with stress σ = 2 kg/mm², 4) annealed in γ-phase after creep tests with t = 550° and σ = 2 kg/mm².

Thus, c.h.t. alone causes 0.8% elongation; creep at 500° and stress of 4 kg/mm² for 4 hours cause 8.4% residual deformation; but c.h.t. under a stress of 4 kg/mm² affords an elongation of 63.8%. This is almost seven times greater than the total deformation from

creep and from c.h.t. without stress and is almost 80 times greater than deformation from c.h.t. without continuously applied stress.

We should note that the total residual deformation during c.h.t. under a stress of 4 kg/mm^2, equalling 63.8%, is two times greater than relative elongation during short tensile tests at 550°. (The temperature of 550°, equalling the top temperature of a cycle, is also the temperature at which relative elongation is at its maximum during short tests in the 20-550° range.)

Residual elongation of the specimens becomes larger with an increase in the number of heat cycles and with the magnitude of the applied load. Thermophysical pre-treatment exerts a substantial influence on the growth of the uranium under the effect of c.h.t. under load. Uranium quenched from the β-phase region undergoing c.h.t. in the 180-550° range with $\sigma = 2$ kg/mm^2 gives a residual elongation equal to 93% (Fig. 6). This is many times greater than deformation from creep at 550° with $\sigma = 2$ kg/mm^2 and is 3.5 times greater than the relative elongation during short tensile tests at 550° (for uranium quenched from the β-phase region σ = 26.3%).

Specimens of uranium with disordered crystallite orientation (annealed from the γ-phase region) were similarly tested. In these specimens we also observe a residual deformation which has increased several times under the common effect of c.h.t. and a continuously applied stress (Figs. 6 and 7).

In the 490-720° range we observe an even greater increase in residual deformation from the common effect of c.h.t. and a continuously applied load (Fig. 8). Thus, after 100 heat cycles without applying a load the uranium specimen elongated by 0.5%; after 100 heat cycles with $\sigma = 0.5$ kg/mm^2, by 15.5%; and during creep tests at both 620 and 720°, by only 0.61% (the period of exposure at each tempera-

ture equalled the duration of 100 heat cycles).

Increasing the external load leads to a rise in residual deformation. Residual elongation after 100 cycles at $\sigma = 1$ kg/mm² with c.h.t. in the α-region amounts to 1.6% (Fig. 7), but with c.h.t. in the 490-720° range it rises to 37.8% (Fig. 8). Thus, with the same stress c.h.t. accompanied by phase transformations gives a residual deformation 23.6 times greater than c.h.t. in the α-region.

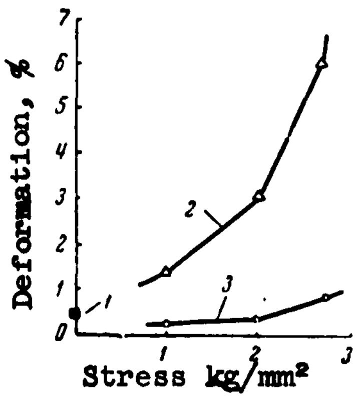

Fig. 7. Effect of continuously applied stress on residual deformation in uranium annealed from the γ-phase. 100 heat cycles in the 180-550° range. Creep tests at 550°. Residual deformation of specimens after 1) heat cycles without load, 2) heat cycles with constantly applied load, 3) creep tests with t = 550° and τ = 14 hours.

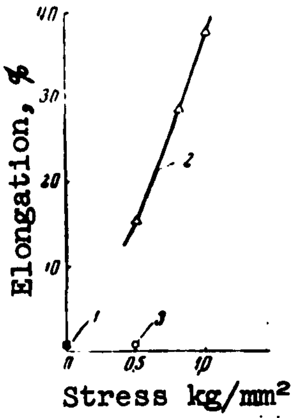

Fig. 8. Effect of continuously applied load on residual deformation in uranium during 100 heat cycles in the 490-720° range and during creep tests. Residual deformation of the specimens after 1) heat cycles without load, 2) heat cycles under load, 3) creep tests with t = 620 and 720° (period of exposure at each temperature equals the duration of 100 heat cycles).

Increasing the heating duration from 1.5 to 3 minutes enlarges residual deformation of uranium specimens during c.h.t. under load (Fig. 9).

In order to clarify at what stage of the cycle the greatest residual deformation of the specimen occurs, we applied loads either only when heating the specimen or only when cooling it. When this was done, the residual elongations proved to be different: the greatest

elongation was obtained when load was applied when the specimen was heated, notwithstanding that during one cycle the period the specimen was under load when being cooled was three times longer than when being heated (Fig. 10).

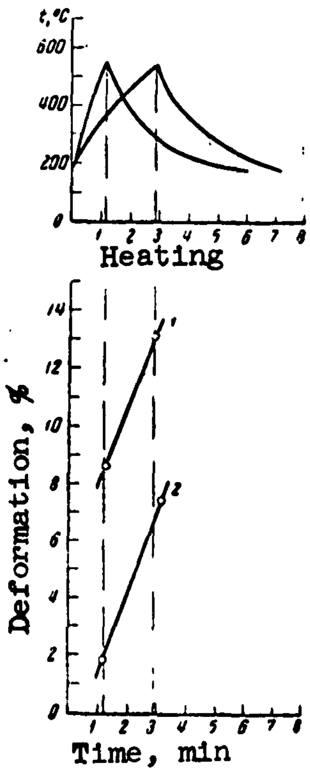

Fig. 9. Effect of duration of heating in 140 heat cycles on residual deformation in uranium rolled in the α-phase. Specimens cut out along the direction of rolling. Residual deformation of the specimens after heat cycles with 1) $\sigma = 2$ kg/mm², 2) $\sigma = 0.8$ kg/mm².

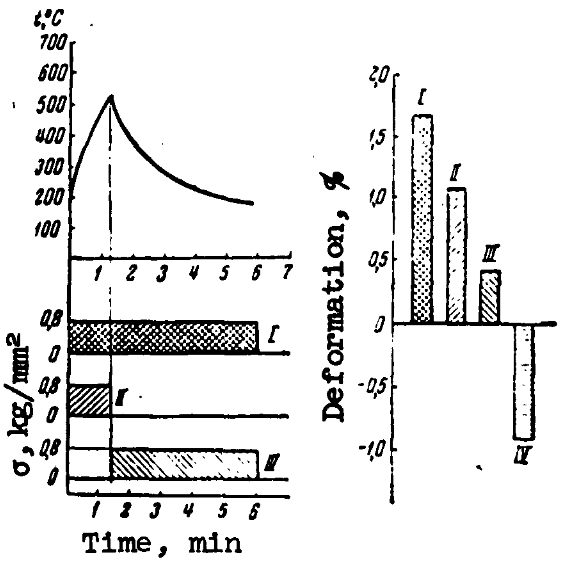

Fig. 10. Effect on residual deformation of uranium rolled in α-region.of application of stress at different stages of the heat cycle (during heating alone or during cooling alone) in 180-550° range Specimens cut out across rolling direction. Residual deformation after 140 heat cycles with application of load $\sigma = 0.8$ kg/mm² I) during whole cycle, II) only while heating specimen, III) only while cooling specimen, IV) without stress.

The total elongation of the specimens under stress during heating alone or during cooling alone corresponds to the elongation of the specimen under load during the whole cycle.

Aluminum, zinc, and alloys of the brass type were tested like uranium, i.e., the magnitudes of residual deformation after three types of tests were compared; but, unlike uranium, the specimens were heated in air; but were cooled in water (see Fig. 1b). Figure 11 shows the results of the aluminum and zinc tests.

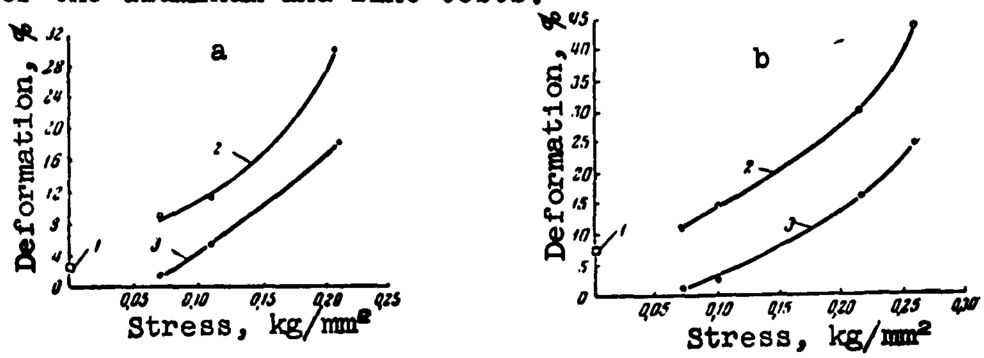

Fig. 11. Effect of continuously applied stress on residual deformation of (a) aluminum and (b) zinc with and without 100 cycles. Residual elongation of specimens after 1) heat cycles without load, 2) heat cycles under load, 3) creep tests.

After 100 heat cycles without external load the specimens elongated by 2.4% for aluminum and 7.5% for zinc. The specimens elongated by 18.4% for aluminum and 15.7% for zinc after creep testing with $\sigma = 0.21$ kg/mm².

Elongation is more substantial after c.h.t. with a continuously applied load. Thus, aluminum specimens elongated by 30.4% after c.h.t. with $\sigma = 0.21$ kg/mm²; and zinc specimens under the same stress, by 26%.

We must note that the magnitude of residual deformation for all the tested specimens after c.h.t. with a continuously applied stress exceeds the total residual deformation resulting from adding the residual deformations during c.h.t. alone without load and during creep tests.

Investigation of α-brass (13.5 wt. % Zn) and β-brass (46.3 wt. %) specimens after 100 heat cycles showed that c.h.t. with continuously applied stress gives a residual deformation exceeding the total residual deformation from c.h.t. alone without load and from creep alone at a temperature equal to the top temperature of the cycle and corresponding to the stress (Fig. 12).

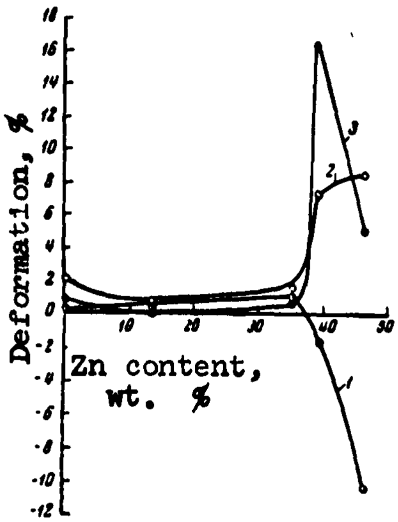

Fig. 12. Effect of continuously applied load on residual deformation of specimens of copper-zinc alloys depending on chemical composition. Residual elongation of the specimens after 1) 100 heat cycles without load, 2) 100 heat cycles under load, 3) creep tests.

In two-phase alloy specimens, e.g., α+β-brass, 39.6 wt. % Zn, we observe a different picture from that in α- and β-brass. In this case the residual deformation resulting from creep tests alone considerably exceeds deformation resulting from c.h.t. with continuously applied load.

Conclusions

1. As a result of the application of slight tension to specimens of uranium, aluminum, zinc, α- and β-brass during c.h.t. there arises considerable residual deformation, which substantially exceeds in value (sometimes by several times) the total deformation from creep and from c.h.t. without application of load.

2. Cyclic heat treatment of transverse specimens of textured sheet uranium in the α-phase temperature region, and also of β-brass without tension, causes contraction of the specimens; but with small external tension causes considerable elongation on their part in the

direction in which the external force acts.

3. As a result of c.h.t. of uranium with a continuously applied load and a transition through the point of phase transformation $\alpha \rightleftarrows \beta$, the residual plastic deformation increases in comparison with the deformation resulting from c.h.t. within the limits of the α-region.

4. In $\alpha+\beta$-brass the residual deformation resulting from tests for creep alone considerably exceeds deformation under the influence of c.h.t. with a continuously applied load. The dimensional change of the specimens is directed toward the action of the applied external force.

5. The considerable change in the magnitude of the residual deformation and even in the sign of the deformation resulting from the effect of small stresses applied to the specimen during c.h.t. is explicable, from our point of view, by saying that on the application of a constant tension to a specimen undergoing c.h.t., the initial stage of the first period of creep, in which the material manifests a heightened capability of deformation, is repeatedly taken advantage of. This heightened capability of deformation is also abetted by the great mobility of the atoms in the period when temperature gradients and stresses are present in the operation of the heat cycle, and also during the transition through the point of phase transformation $\alpha \rightleftarrows \beta$.

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